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Neck and abdominal muscle activity during a sniff

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Summary Measurement of sniff nasal inspiratory pressure (SNIP) is now used widely as a simple, non-invasive assessment of global respiratory muscle strength, even though the technique evolved originally from measurements of trans-diaphragmatic pressure (P_{di}) that reflect the status of the diaphragm. The relative participation of major respiratory muscles, apart from the diaphragm, in the generation of SNIP is not known. Therefore, we examined the activity during a sniff of both neck and abdominal "accessory" muscles. In seven young adults we implanted fine wire EMG electrodes under direct vision with high-resolution ultrasound into scalene, sternocleidomastoid, trapezius, and transversus abdominis. SNIP was measured during sniffs that were short and sharp, from low to maximal intensity, in both standing and supine postures. Mean maximum SNIP was $-105.6\,\mathrm{cm\,H_2O}$ (SD 32.9) in supine and $-94.5\,\mathrm{cm\,H_2O}$ (26.6) in the standing posture, (difference NS). In every subject, scalene activity appeared even at the lowest SNIP, and increased linearly with increasing SNIP. Sternomastoid activity appeared at higher SNIP levels in three of seven subjects. By contrast, trapezius activity was never present at low SNIP, and appeared in only 2 subjects at maximum SNIP. Sniff abdominal expiratory activity was inconsistent with no activity of transversus in four of seven subjects even at greatest SNIP. Thus, we observed differential activation among these non-diaphragm respiratory muscles during SNIP; while some accessory muscles were very active, others were unlikely to contribute to generation of SNIP. Clinically, this indicates SNIP will be impacted unequally by loss of function of specific respiratory muscles.
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Introduction

The technique of measuring sniff nasal inspiratory pressure (SNIP) has achieved wide acceptance as a simple, non-invasive assessment of inspiratory muscle strength[1–5] in recent years. An attraction of the SNIP technique is that simple measurement of nasopharyngeal or mouth pressure during a maximal, short sniff reliably estimates esophageal pressure during a sniff[1] without the need for an esophageal catheter. In general, a sniff-generated pressure measured at either site offers an alternative to maximal inspiratory pressure against an occlusion as an assessment of inspiratory muscle strength.[1,6,7]

Historically, the current SNIP technique evolved from measurement of trans-diaphragmatic pressure (P_{di}) during a sniff as a means of detecting diaphragm fatigue.[8] Somewhat later, the measurement of esophageal pressure (P_{es}) during a maximal sniff was found to be a useful confirmatory test of overall respiratory muscle dysfunction.[6] Many subsequent studies established the convenience and utility of the SNIP in the assessment of a wide variety of disorders afflicting respiratory muscles, including acute respiratory failure, muscular dystrophy and other neuromuscular disorders, and lung

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volume reduction surgery.[2–5] Thus, SNIP has been accepted as a clinical indicator of global respiratory muscle strength, even though the technique derived originally from a specific measurement (P_{di}) related closely to the status of a single muscle, the diaphragm.

The extent to which each major respiratory muscle contributes to SNIP values may be important in our interpretation of SNIP. Clinically, if we interpret changes in SNIP values to faithfully reflect changes in overall, global, respiratory muscle strength, then we assume that most respiratory muscles have a roughly equivalent influence on the SNIP. If this assumption is not correct, then SNIP could be very insensitive to serious loss of function of individual respiratory muscles. Alternatively, if SNIP is profoundly influenced by the diaphragm compared to other muscle groups, then a minor loss of diaphragm function without any deterioration of other respiratory muscles would still result in a significant loss of SNIP, even though overall muscle function had not changed very much.

So if SNIP is to be interpreted as a robust indicator of global respiratory muscle function, we must identify the contributions of the various non-diaphragm respiratory muscles to the SNIP. To what extent do respiratory muscles, other than the diaphragm, contribute to SNIP? Before we can quantify pressure contributions, as a first step, what is the relative electromyographic (EMG) activity of individual respiratory muscles during a sniff? To date, there is very little information about individual respiratory muscle activity during a sniff, and the actions of certain muscles during the sniff seem to be quite unlike their usual activity during breathing. For example, a previous study[9] suggested that both sternomastoid and rectus abdominis are strongly active during a sniff, even though these two muscles are known to show very little activity even during highly stimulated ventilation.

The aim of the present study was to ascertain whether the accessory muscles of neck and abdomen are active during the sniff maneuver, using direct measurement by fine wire electrodes. Specifically, are the neck muscles including the scalene, sternocleidomastoid, and trapezius, active during a sniff? Does transversus abdominis, which is the primary, expiratory muscle of the abdomen, actively participate in the inspiratory sniff, as well?

Methods

We studied seven young male subjects (age: 20–27 year, height: 157–179 cm, weight: 55–73 kg), who were unaware of the scientific purposes of this study. All subjects were healthy, without any history of pulmonary or neuromuscular disorders. Each subject gave informed consent to participate in the study, which was approved by Kitasato University human ethics committee.

Electrode insertion

Details of our fine wire EMG techniques are published elsewhere.[10] Briefly, the neck muscle EMG recording electrodes were fashioned from 80 μm polyurethane-coated platinum fine wire (Unique Medical, Tokyo, Japan). These were inserted by a modified Basmajian technique,[11] approximately 10 mm apart, along the axis of the fiber bundles of scalene (SCLN), sternocleidomastoid (STERNO), and trapezius (TRAPZ) and transversus abdominis (TA) muscles, using a guide needle under direct vision provided by high resolution 7.5 MHz ultrasound echograph (EUB-340, Hitachi, Tokyo, Japan), while the subjects were awake and reclining in the supine position on a tilt bed. The sites of insertion were: left SCLN, approximately: 3 cm above and 1 cm posterior to left mid-clavicle, STERNO, in the middle of the muscle body and 3 cm above the anterior head, TRAPZ, 4 cm above and 4 cm posterior to left midclavicle, and TA, 1 cm below the left costal margin on the anterior axillary line. As described previously,[10] a series of respiratory and non-respiratory maneuvers was performed after insertion to confirm correct placement and recording fidelity of the fine wire electrodes. Maximal or near-maximal activity was elicited from: SCLN, by sustained TLC maneuver, STERNO, by neck flexion attempting to place chin on chest against resistance applied to the forehead, and TRAPZ, "shrugging" shoulders against resistance. For TA, maximal or near-maximal activity EMG activity was elicited during forced expiration from functional residual capacity to residual volume. All these respiratory and non-respiratory maneuvers were repeated again at the conclusion of the experiment to confirm that wire position and fidelity of each EMG was unchanged.

Measurement techniques

Sniff nasal inspiratory pressure (SNIP) was measured during sniff through a catheter that occluded one nostril, while the contralateral nostril remained open. The catheter was attached to a pressure transducer (DX312, Omeda, Singapore) then amplified (AD-601G, Nihon-Kohden, Tokyo, Japan). Sniffs were initiated from functional residual capacity. Using visual feedback of SNIP on the monitor, subjects were asked to perform sniffs that were: short and sharp, from low to maximal intensity, in both standing and supine postures. We encouraged practice and provided enthusiastic coaching and instruction to elicit maximal effort during the sniffs. The technique for supine recordings aimed to standardize position and ensure maximum relaxation of the muscles, to prevent any confounding effects of posture on length, activation, and mechanical advantage of individual muscles. The subjects reclined on a hard, flat tilt table with one singly folded towel only under the back of the head. Recordings were undertaken while standing since clinically sniff is often measured in the standing posture. To minimize variability in muscle activation related to posture change from supine to standing, we used a tilt table to bring the subject to the vertical position, then the subject moved head and trunk forward approximately 2 cm, just sufficient to avoid touching the vertical tilt table.

Raw EMG signals from the electrodes were amplified (Model 7S12, NEC Sanei, Tokyo, Japan), band-pass filtered (Bessel type, 10 Hz to 2 kHz; NF Filters, Tokyo, Japan), and recorded with SNIP onto a digital audio tape (DAT) data recorder (Model PC116, Sony, Tokyo, Japan). At the same time, the EMG signals were rectified and processed by a resistance–capacitor with a time constant of 50 ms (Model EI-601G, Nihon-Kohden, Tokyo, Japan) to provide continuous moving average EMG of SCLN, STERNO, TRAPZ and TA. The moving average signals and SNIP were gathered directly to hard disk on a microcomputer using acquisition software (DataSponge, Bioscience Analysis Software, Calgary, Alberta) and a single board A/D system (Model MIO-16-H-9, National Instruments, Galveston, TX) for subsequent examination using a series of dedicated analysis programs written by one of the authors (PE).

EMG analysis

Maximal EMG (EMG_{max}) of these inspiratory and expiratory muscles was defined as the greatest moving average (MAVG) EMG activity recorded from each individual muscle during respiratory or non-respiratory maneuvers, for each subject, as described above. Moving average EMG values of each muscle during the SNIP measurements were expressed as $\%EMG_{max}$.

Statistical analysis

After calculation, mean values were exported for review to spreadsheet software (Microsoft Excel, Microsoft, Redmond, WA) to output Figs. 3 and 4, and to chart software (SigmaPlot version 4.0, San Rafael, CA) to generate Figs. 1 and 5. Values were analyzed statistically using the PC version of SAS.[12] The relationship between the EMG response of each muscle and SNIP was calculated by linear regression using the method of least squares.[13] Maximum SNIP, and the slope of MAVG EMG activity vs. SNIP for SCLN and STERNO, was compared in supine and standing postures by paired *t* test.

Results

Discomfort was minimal during fine wire electrode insertion, maximal respiratory and non-respiratory maneuvers, and sniff measurements; no subject required analgesia. Values of maximal EMG activity recorded during respiratory and non-respiratory maneuvers both before and after the series of sniff measurements, were not different in any subject. In addition, at the conclusion of the experiment, when each electrode was removed we confirmed that the electrode had remained buried to exactly the same depth as the guide needle had been advanced initially with ultrasound.

For each subject, 25–45 sniffs of varying intensity were collected in both standing and supine posture. We selected for analysis only sniffs of less than 500 ms duration. Mean maximum sniff nasal inspiratory pressure (SNIP) in seven subjects was -105.6 cm H_2O (SD 32.9) in supine and -94.5 cm H_2O (26.6) in the standing posture, which was not significantly different between postures (Fig. 1).

SNIP and raw EMG of scalene and sternocieldomastoid

Even at the lowest SNIP pressures (-20 cm H_2O), SCLN raw EMG activity was apparent, and SCLN EMG increased thereafter with each stepwise increment in SNIP. By contrast, STERNO raw EMG activity was not present at low SNIP but did appear at increasing SNIP pressures of approximately -40 cm H_2O. Thereafter STERNO EMG activity increased as SNIP increased. The progression of EMG activity with SNIP for both SCLN and STERNO muscles is illustrated for a typical subject in Fig. 2.

Relationship between increasing SNIP and neck muscle moving average EMG

The relationship between increasing SNIP, and the activity of the neck muscles expressed as moving average EMG, is illustrated in Fig. 3 (same subject as Fig. 2 for consistency). Typically, SCLN EMG appeared even from the lowest SNIP (approximately $-10\,cm\,H_2O$) and increased linearly with increasing SNIP (R^2 =0.91). The activity of STERNO EMG was similar with increasing SNIP, but activity began only at higher pressures then increased linearly as SNIP increased. By contrast, TRAPZ exhibited virtually no measurable EMG activity even at maximal SNIP.

These same SNIP EMG relationships were seen in all seven subjects with only minor variation, as summarized in Table 1. In seven subjects, SCLN EMG activity appeared even from the lowest levels of SNIP, and increased linearly with increasing SNIP. STERNO EMG appeared at slightly higher SNIP levels so that only three of seven subjects showed STERNO EMG at SNIP of $-20\,cm\,H_2O$, and STERNO EMG then increased linearly with increasing SNIP. By contrast, TRAPZ EMG activity was never present at low SNIP pressures, and appeared even at the highest SNIP pressures in only two of seven subjects.

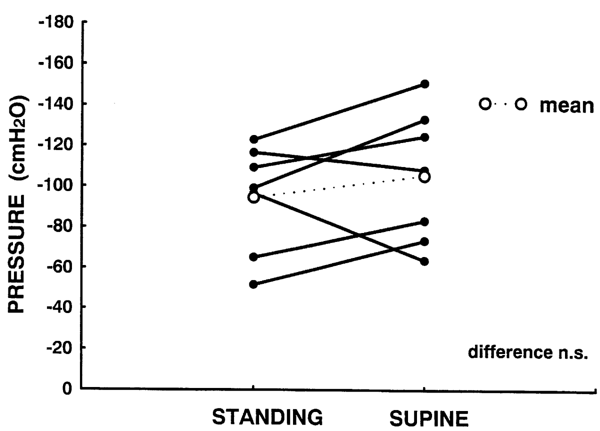

Figure 1 Maximum sniff nasal inspiratory pressure (SNIP) with different postures. Maximum sniff inspiratory pressure (SNIP) on y-axis. Open circles and dotted line show group mean; solid circles and solid lines show individual subjects, in standing and supine postures. Maximum SNIP was not different between postures.

Impact of posture on SNIP and neck muscle EMG

The strong linear relation between neck EMG activity and SNIP persisted in both standing and supine postures, but the relative increase in EMG per change in SNIP, i.e. the slope, was greater while standing. This is shown for a single subject in Fig. 4 and summarized for the group in Figs. 5(1) and 5(2). Specifically, for all subjects the mean slope of the linear regression between SCLN EMG activity and SNIP ($\Delta\%EMG_{max}\Delta$ SNIP) in Fig. 5(1) was $-0.73\%/cm\,H_2O$ (SD 0.27) in standing and $-0.53\%/cm\,H_2O$ (0.13) in the supine posture (difference $P<0.05$). In Fig. 5(2), STERNO EMG also appeared to increase more rapidly with increasing SNIP in the standing posture compared to supine. Although the postural difference for STERNO was not significant with these seven subjects, the trend with standing posture may have been significant with a larger sample.

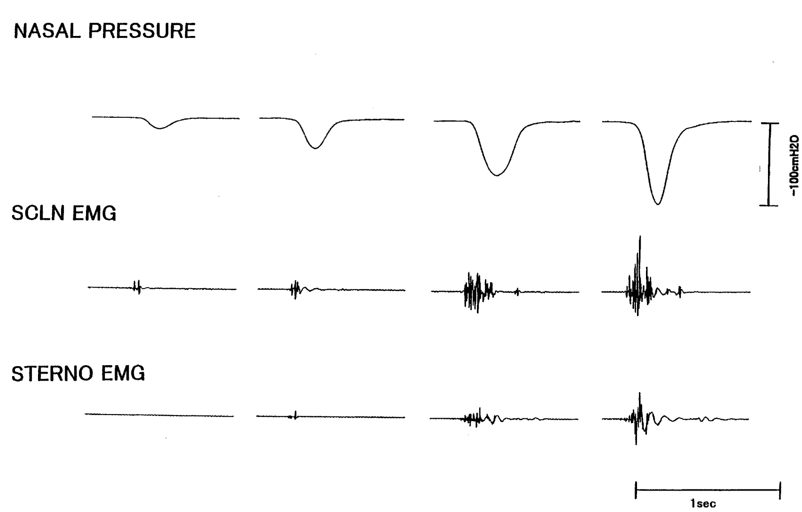

Figure 2 SNIP and raw EMG of neck muscles. Sniff nasal inspiratory pressure (SNIP) is shown in the top trace. Raw EMG activity of scalene (SCLN) and sternocleidomastoid (STERNO) is shown in middle and bottom traces. The first sniff is approximately $-20\,cm\,H_2O$, the second $-40\,cm\,H_2O$, third $-60\,cm\,H_2O$ and fourth $-100\,cm\,H_2O$, respectively. The duration of each sniff is less than 500 ms. In SCLN, raw EMG was detectable even at low SNIP and increased with stepwise increments in SNIP. In STERNO, raw EMG was not present at minimal SNIP, appeared at $-40\,cm\,H_2O$, then increased incrementally with SNIP.

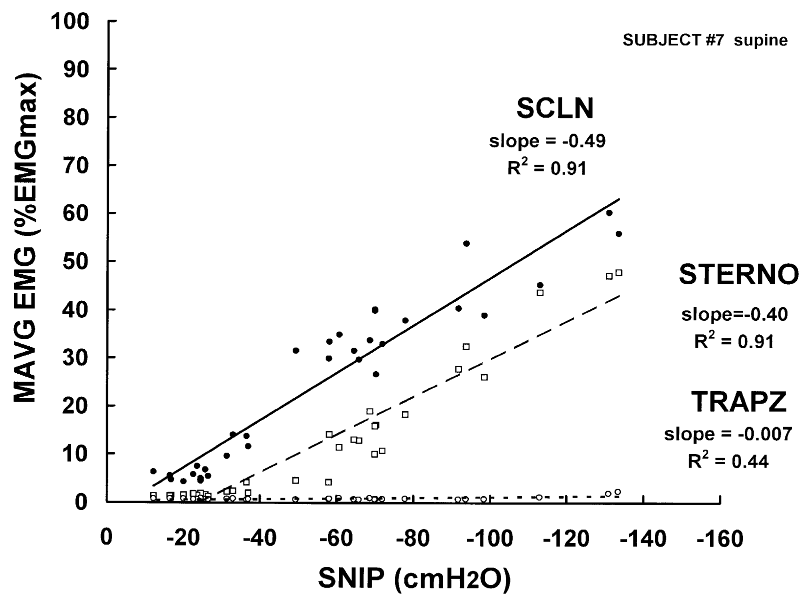

Figure 3 SNIP and moving average EMG in neck muscles, in the supine position. Moving average EMG is shown on *y*-axis as percent of maximum EMG (%EMG_{max}). Sniff inspiratory nasal pressure (SNIP) is shown on *x*-axis. Solid circles and solid line represent scalene (SCLN), open squares and broken line show sternocleidomastoid (STERNO), and open circles with dotted line show trapezius (TRAPZ), respectively. SCLN EMG activity was present from lowest SNIP and a strong linear relation exists between increasing SNIP and EMG activity. STERNO EMG activity appeared from approximately −30 cm H_2O SNIP, then increased linearly with SNIP. TRAPZ showed minimal EMG activity at any SNIP.

Table 1 Presence of neck muscle EMG activity during sniff nasal inspiratory pressure.

	Number of subjects	EMG activity present		Significant linearity between EMG and SNIP (R^2>0.85)
		At −20 cmH_2O of SNIP	At maximum SNIP (−100 cmH_2O)	
SCLN	7	7	7	7
STERNO	7	3	7	7
TRAPZ	7	0	2	2

Values are number of subjects. SCLN, scalene; STERNO, sternocleidomastoid; TRAPZ, trapezius.

Relationship between SNIP and TA EMG activity

Besides the inspiratory EMG activity of the neck muscles, the sniff maneuver was accompanied by some inconsistent EMG activity recorded from the abdominal expiratory muscle, the transversus abdominis (TA) in a few subjects. Sniff abdominal expiratory activity was not uniform. In three of seven subjects, some TA EMG activity appeared by moderate SNIP pressures and increased with increments in SNIP. However, in four of seven subjects, TA EMG activity never appeared even at the highest recorded SNIP (Fig. 6).

Discussion

These results show that some accessory muscles of respiration are very active during a sniff, while others do not contribute. Specifically, the SCLN showed significant activity beginning from the lowest pressures of SNIP, increasing linearly with increasing SNIP. STERNO was only modestly active, with some activity at higher SNIP, while TRAPZ was essentially inactive during sniffing. The abdominal expiratory muscle was inconsistent, either showing no activity at all or minimal activity at only the highest SNIP. The activity of these muscles was greater in standing than supine postures with a sniff.

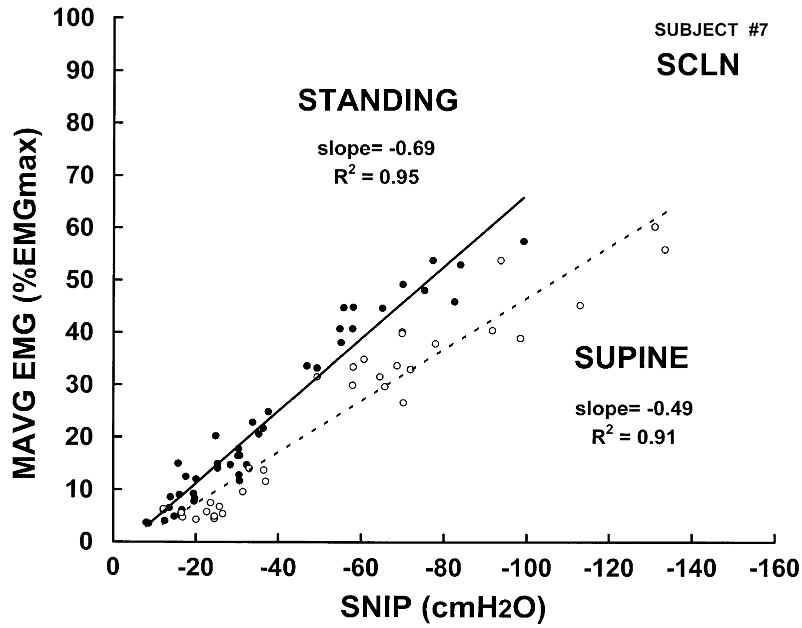

Figure 4 Relation between scalene EMG and sniff nasal inspiratory pressure in different postures. Solid circles and solid line represent scalene (SCLN) activity while standing, open circles and broken line show supine activity. Other conventions as in Fig. 3. Both standing and supine, SCLN EMG activity showed a strong linear relation with increasing SNIP.

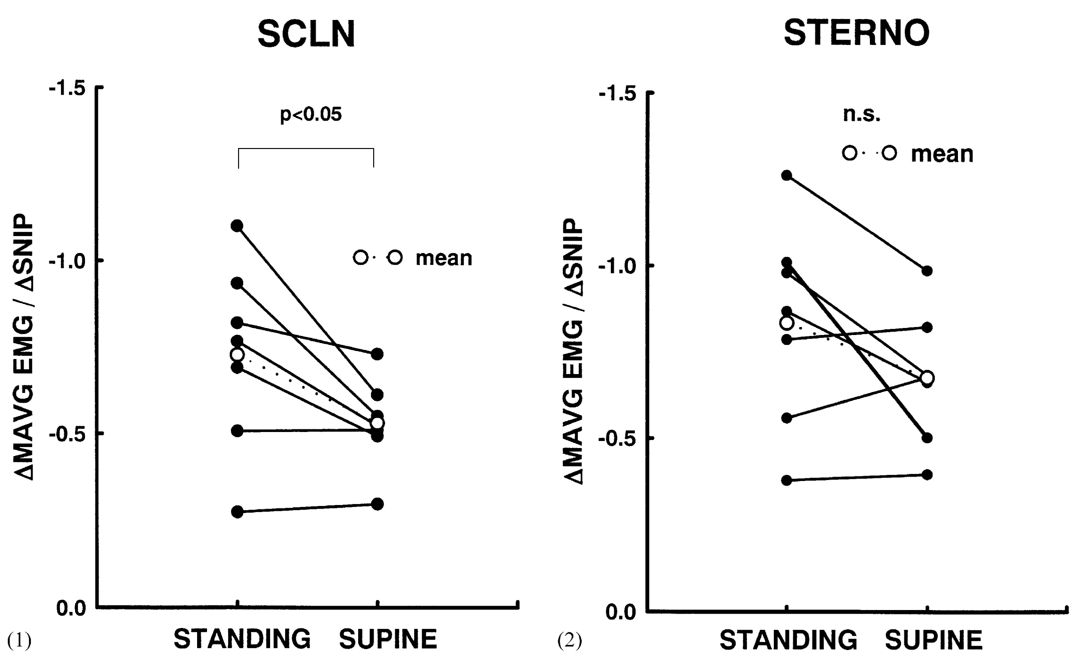

Figure 5 (1) Relative change in scalene EMG and SNIP in different postures. Change in scalene (SCLN) moving average EMG per cmH_2O change in sniff nasal inspiratory pressure (SNIP) (ΔMAVG EMG/ΔcmH_2O) is shown on y-axis. Other conventions as in Fig. 1. The slope of the relationship between SCLN EMG and SNIP was significantly greater while standing ($P<0.05$). (2) Relative change in sternocleidomastoid EMG and SNIP in different postures. The slope of STERNO EMG vs. SNIP was not different between postures.

Validity of SNIP values

In this study, mean maximum SNIP was -105.6 cm H_2O (SD 32.9) and -94.5 cm H_2O (26.6) in supine and standing postures, respectively. These values are comparable to the results from Heritier and colleagues[1] where mean maximum sitting SNIP was -85 cm H_2O in normal subjects.

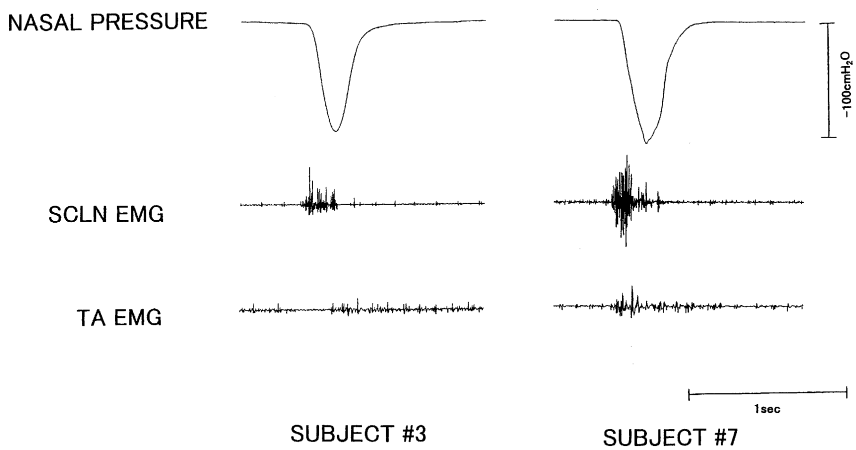

Figure 6 Abdominal and neck muscle EMG and sniff nasal inspiratory pressure. Sniff nasal inspiratory pressure (SNIP) is shown in the top trace. Raw EMG activity of scalene (SCLN) and transversus abdominis (TA) are shown in middle and bottom traces, respectively. As seen in the left column, EMG activity of TA was not present at maximum SNIP in subject 3. In the right column, EMG activity of TA was present at maximum SNIP in subject 7.

From the equation predicting maximum SNIP developed by Uldry and Fitting,[14] based on the age and gender of our subjects the lowest predicted maximum SNIP for our group is −78.5 cm H_2O. In fact, two of our subjects demonstrated a SNIP lower than their predicted lowest value. The explanation for this modest discrepancy in SNIP values for our group probably lies in the sample group we studied. It is known that inspiratory muscle strength is significantly different between North American/Caucasian and Asian subjects. Nishimura and colleagues[15] suggested that maximal inspiratory mouth pressure (P_{imax}) in Japanese males was 82% of the values expected for North American subjects calculated from the work of Black and Hyat.[16] Moreover, Chan et al.[17] studied sniff P_{di} and P_{imax} values in Chinese subjects, which were equivalent to the values we obtained in our Japanese subjects. We did not find any significant difference between values of maximum SNIP in sitting and supine positions in our subjects. This same equivalence of SNIP despite different posture has been noted in other studies.[1,14]

Sniff measurement of inspiratory muscle strength

The sniff maneuver with measurement of transdiaphragmatic pressure (P_{di}) began as one method of assessing diaphragm function.[18] The same group extended the utility of the sniff, suggesting that measurement of esophageal pressure (P_{es}) during a maximum sniff was a useful test of global inspiratory muscle strength among patients with diverse pulmonary abnormalities.[6] Later, another group of investigators noted that different pressures measured during the sniff provided somewhat different information about respiratory muscle function. According to those investigators, P_{es} during a maximal sniff reflected global inspiratory muscle strength whereas P_{di} during a maximal sniff more closely reflected diaphragmatic strength.[19,20] In any case, sniff esophageal pressure was recognized as a valid indicator of overall inspiratory muscle strength that was more comfortable and convenient than maximal inspiratory pressure against an occlusion (P_{imax}).[1] In recent years, SNIP measurement has largely supplanted sniff P_{es}, since the SNIP closely tracks sniff P_{es} and is less invasive.[2–4]

Despite widespread usage of SNIP as a surrogate for P_{es} and indicator of global muscle strength, we know very little about the relative contributions of various respiratory muscles to the sniff and SNIP. The aforementioned studies describing the evolution of SNIP from sniff P_{di} suggest that diaphragm has the predominant influence on SNIP, but other respiratory muscles undoubtedly contribute—although their relative contribution is unknown. For example, in a recent study by Polkey and colleagues,[21] sniff P_{es} was significantly greater than twitch P_{es} elicited using magnetic stimulation of the phrenic nerve, and sniff P_{di} was significantly greater than twitch P_{di}. This observation suggests that both sniff P_{es} and sniff P_{di} provide more global information about respiratory muscle function including the chest wall and neck, and not just diaphragm. Presumably, SNIP values provide equivalent extra-diaphragm information. The higher values for the sniff pressures are especially significant in light of the action of cervical magnetic stimulation, which is known to activate muscles of the upper thorax in addition to diaphragm. Apparently the sniff activates not only the muscle set elicited by the magnetic stimulator, but additional respiratory muscles as well.

Clinical interpretation of SNIP usually assumes that important loss of function of individual non-diaphragm muscles will be reflected appropriately in decreased SNIP pressures, and that minor diaphragm weakness without any weakness in other muscles will not disproportionately impact SNIP. If this is not correct then our interpretation of SNIP must be circumspect. For example, what would be the effect on SNIP values of the different types of muscular dystrophy? Probably Duchenne dystrophy allows relative preservation of the diaphragm until later in the disease,[22] compared to limb-girdle dystrophy where involvement of the diaphragm occurs relatively early. If SNIP values are disproportionately influenced by the diaphragm compared to other respiratory muscles, then SNIP values may be very sensitive to loss of function in Duchenne dystrophy but SNIP values may be insensitive to deterioration in limb-girdle dystrophy. The results in this study show that accessory muscle activity is very heterogeneous during the sniff. However, the SNIP values do seem to generally track the most active muscles. Thus this work also provides some reassurance that the SNIP will continue to track net "global" inspiratory muscle activity, even as relative muscle contribution changes in disease. Although we know that SNIP values change in respiratory failure and various respiratory abnormalities, studies examining the relative sensitivity of SNIP in different disorders will be difficult. Therefore, it would be helpful to know the relative contribution of the major respiratory muscles to a sniff. As a first step, it would be informative to understand at least the relative activity, as expressed by EMG, of the various major respiratory muscles during a sniff.

Even as we study the relative activity of specific respiratory muscles during the sniff, we must recognize that our understanding of the contribution of particular muscles to inspiratory pressure generation and the sniff maneuver is limited. For example, we cannot know whether weak patients will maximally recruit all their remaining muscles in a sniff. We might presume that weak patients recruit muscles which contribute to the SNIP in rough proportion to the relative activity of the individual muscles during resting breathing, but there is no assurance of that. In any case, we must be careful about extrapolation of any measurement of respiratory muscle activity in normal subjects to the sniff in weakened patients.

Activity of respiratory muscles during sniff

Very little is known of the EMG activity of respiratory muscles during a sniff, and what little information we have suggests that respiratory muscle action during the sniff is quite different that during breathing.[9] During the sniff, Nava and colleagues measured EMG activity of diaphragm using an esophageal electrode, and of STERNO, parasternal intercostal, and rectus abdominis using surface electrodes. They suggested that significant EMG activity of diaphragm, parasternal, STERNO and even rectus abdominis appeared during maximal sniffs. Moreover, the activity of STERNO and rectus was striking; the STERNO was as active during the sniff as during a maximal inspiratory maneuver while rectus abdominis achieved 26% of the activity recorded during a maximal expiratory maneuver. Those results are much different than the known recruitment of those muscles during breathing and quite different than the results in our study. Among the neck muscles, we found that STERNO showed only modest activity, very much less than maximum, during a sniff. As for the abdominal muscles, we found the activity of the transversus abdominis was inconsistent and minimal compared to maximal expiratory activity. Since the transversus is known to be the most active abdominal respiratory muscle while the rectus is the least active,[10] the extensive activity of the rectus during a sniff in the aforementioned study is surprising. The use of surface EMG electrodes in the earlier study probably accounts for the differing results, since surface electrodes of chest wall or abdomen have very limited specificity for measuring EMG from individual muscles. Moreover, in the earlier study the possible influence of posture on the rectus is not known; postural activation of rectus could confound the sniff recordings. In general, posture is an important and potentially confounding variable in this type of measurement. Techniques must standardize position and prevent inadvertent, partial activation of the muscles because of position. Otherwise pre-sniff activity and resting length of specific muscles will be altered with an immediate impact upon the contribution of the muscle towards SNIP.

In this investigation, we observed differential activation of the neck muscles during various levels of sniff. This differential activation of these neck muscles is consistent with the differential activity they are known to exhibit during stimulated breathing. The SCLN was recruited even from very low SNIP in all subjects, while STERNO was active at maximum SNIP in all subjects but at lower SNIP in only three of seven subjects. Most subjects did not show muscle activity of TRAPZ. Of the three neck muscles, SCLN is known to be the primary inspiratory muscle,[23,24] with comparatively little activity of STERNO during inspiration. TRAPZ is hardly active during inspiration even among patients with severe chronic obstructive lung disease.[25] Thus, the differential activities of the neck and abdominal muscles we recorded during the sniff were analogous to the relative activity of these muscles during ventilation.

Acknowledgements

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